Note on the Origin of the Highest Energy Cosmic Rays.

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In this note we argue that the galactic model chosen by E.-J. Ahn, G. Medina-Tanco, P.L. Bierman and T. Stanev in their paper discussing the origin of the highest energy cosmic rays, is alone responsible for the focusing of positive particles towards the North galactic pole. We discuss the validity of this model, in particular in terms of field reversals and radial extensions. We conclude that with such a model one cannot retreive any directional information from the observed direction of the cosmic rays. In particular one cannot identify point sources at least up to energies of about 200 EeV[1] . Therefore the apparent clustering of the back-traced highest energy cosmic rays observed to date cannot be interpreted as an evidence for a point source nor for the identification of M87, which happens to be close to the North pole, as being such a source.

It was recently claimed [1] that the Ultra High Energy Cosmic Rays (UHECR) observed up to now, may originate from a common source located in the direction of the North pole of our Galaxy; the M87 cluster (Virgo) being the best candidate for such an emitting object. This conclusion was drawn from the result of the back-tracing of the 13 highest energy cosmic rays observed to date (assumed to be protons, or helium nuclei for the most energetic ones) in a modeled galactic magnetic field. In their study the field originates from a "galactic wind" (analogous to the solar wind) extending far away from the visible part of the galactic disk.

In this paper we study the mathematical properties of such a field, and show that the observed convergence is an intrinsic property of the field model, and not an evidence of a unique, pointlike source for the highest energy cosmic rays.

1. Focussing properties of the proposed magnetic wind

As far as ultra-high energies (over 100 EeV) are concerned, the bending effects are dominated by the long range behaviour of the galactic field. In the model proposed in [1], the asymptotic field, in spherical coordinates, is purely azimuthal and reads :

$$B_\varphi = B_\odot r_\odot \frac{\sin\theta}{r}$$

where the normalization constant $B_\odot r_\odot = 70\ \mu$G.kpc is defined from the local value of the field in the Solar system. The bounds of the region where the galactic wind extends are not well defined; the authors use 1.5 Mpc in their numerical simulations.

The most important feature of such a field (in the absence of a cutoff on r) is that the bending integral $\int B_\varphi\, dr$ is divergent in any radial direction except the polar axis. As a result, whatever the energy, a charged particle can never escape to infinity in a direction other than a pole. In practice, this strong focussing effect is limited by the cutoff, which therefore plays a crucial role. Using the field and radial limits given above the bending integral is about $500 \times \sin\theta$ EeV along a radial trajectory. In other words particles of 100 EeV will only escape within a cone of less than about 10 degrees around the polar axis.

When considering particles of a given sign the orientation of the radial component of the Lorentz force depends on the polar projection of the ve-

[1]EeV for Exa electron Volts or 10^{18}eV

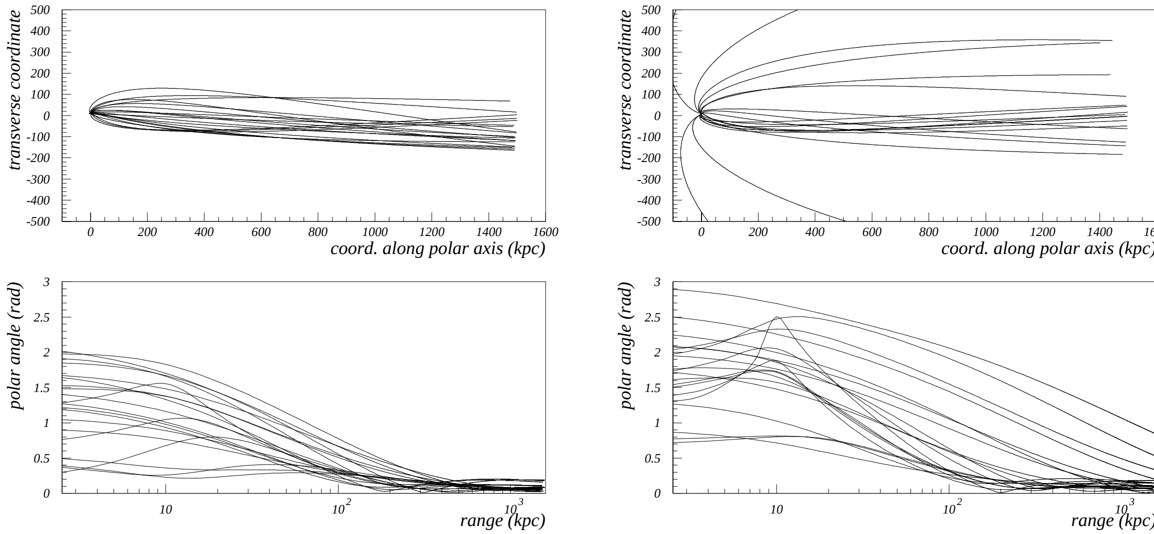

Figure 1. Trajectory of protons of 100 to 160 EeV, back-traced from the Earth's northern (left) and southern (right) hemispheres, the Galactic North pole is to the right. Top : Transverse coordinate projected on the galactic meridian plane containing the Earth versus range. Bottom : Polar angle versus range.

locity, therefore the "positive" pole (as defined by the orientation of curl $\vec{B}$) is focussing, while the "negative" pole is antifocussing.

These features are intrinsic to the field model (especially its slow decrease with the distance) and we can suspect that the convergence of the trajectories found in [1] is therefore not related to any specific property of the observed set of highest energy cosmic rays.

2. Numerical simulations with random data

To confirm this hypothesis, we have numerically back-traced, in the field model of Ref. [1], a _random_ set of cosmic rays drawn from a uniform distibution on the (Earth) sky. As most of the observered high energy events are actually concentrated around 10^{20} eV, and since the authors of [1] have further assumed that the two highest energy events could be Helium nuclei the range of magnetic rigidity of the observed data sample is quite narrow. For a fair comparison we have therefore generated a sample of protons with a flat energy distribution ranging from 100 to 160 EeV.

As expected the trajectories drawn on Fig.1 clearly show the strong focussing effect of the field. Most of the focussing take place over the first few 100 kpc as mentioned in [1]. We have drawn separately the trajectory for particle reaching the Earth's northern hemisphere and reaching the southern one. The focussing effect is stronger and faster for rays originating from the north[2] which is expected given the configuration of the Earth's rotation axis with respect to the galactic center. Using a random population we obtain the same behavior as in [1] showing that the focussing is a property of the field and not of the events.

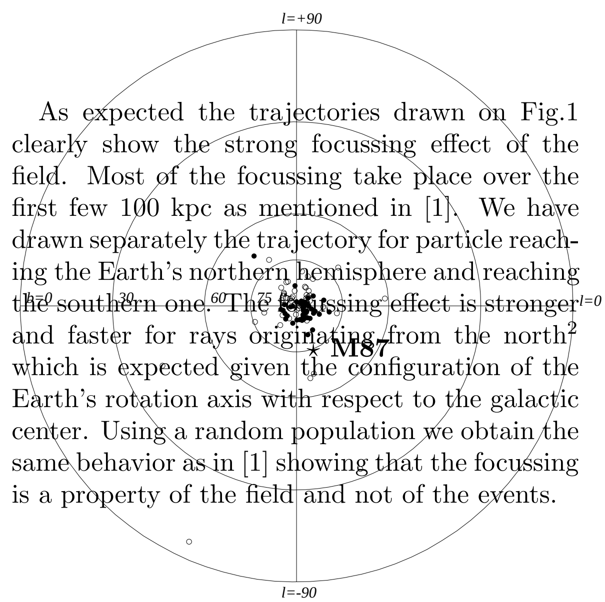

Figure 2. A representation similar to the plot of Ref [1]. Black (open) circles are for rays hitting the Earth's northern (southern) hemisphere.

[2]The 13 events used in [1] were all observed in the northern hemisphere, which is where the largest detectors are installed.

3. Discussion and conclusion

First the validity of the model may be questioned: if there are reversals of the azimuthal component of B in the galactic disk (as acknowledged in [1]), how can the wind remain consistent with a "coherent" parametrization $\sin\theta/r$ at long distances (several 100 kpc, much more than the distance between regions with reversed fields) ? Normally one would expect some destructive interferences between the wind contributions coming from differents parts of the disk, hence an intensity decreasing faster than $1/r$; the argument that most cosmic rays are observed in the direction opposite to the galactic center (where no reversal occurs) is not valid, because their bending depends mainly on the long range behaviour of the field.

If however the model of Ref.[1] is true, then the accumulation of events at the pole is not at all an evidence for a pointlike source of the observed rays. This model only demonstrates that our sensitivity on extragalactic charged particles might be limited to a small solid angle (decreasing with energy) around the galactic polar direction, whatever their initial origin could be.

One should note that even if the extragalactic flux is isotropic the integrated luminosity at Earth would be the same with or without this galactic wind. Despite the strong dispersion in the original directions the restriction of the angular acceptance due to the focussing effect is compensated by the collecting area.

Addressing the question of the active galaxy M87 (Virgo A) as a possible source of UHECR, the only possible affirmative conclusion is: *if* the field model of [1] is valid, *and if* the sources are known pointlike objects, a possible candidate is M87. However, as acknowledged in [1], this scenario implies a regular transverse magnetic field from here to Virgo, i.e. over a length of about 20 Mpc, of about 2 nanogauss. Therefore the overall system would behave like a spectrum analyzer : a magnetic spectrometer (the transverse field) followed by a collimator (the Galactic field), strongly selecting the initial momentum of the cosmic rays.

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REFERENCES

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